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Then and now – how concert hall design of the 1960s and ‘70s compares with the present

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Introduction

The body of this paper compares the concert hall designs from the 1960s and ‘70s with the situation today. Among the former, the de Doelen Concert Hall of 1966 can be considered an acoustic success. One of its most obvious features is the extensive use of scattering surfaces. In this author’s view the value of scattering treatment remains one of the unanswered questions in concert hall acoustics.

This paper however begins with some new results on that other issue for concert halls: the acoustics for the performers, an as yet not fully resolved area.

Preferred conditions for orchestral musicians on concert hall stages

A three-year study of the acoustics of concert hall stages has recently been completed but results remain to be published in journals. A summary was presented at an auditorium acoustics meeting in October 2008 (Dammerud and Barron, 2008). The study involved working with the English professional orchestra: the Bournemouth Symphony Orchestra.

An early realisation in this study was that it is necessary to distinguish between acoustic conditions suitable for chamber music and those for a symphony orchestra. A key issue for a large orchestra is hearing other players and, at least for musicians playing on a flat floor, sound is severely attenuated when it has to propagate through a group of players, Figure 1.



Figure 1. Sound propagation ‘through’ an orchestra.

The attenuation due to the presence of musicians is a high frequency effect and reaches about -12 dB at 2 kHz over a distance of 12 m. This particular problem does not exist with small groups of performers.

An obvious response to the attenuation problem is to consider introducing surfaces to provide compensating sound reflections. An obvious location is to place a reflector over the orchestra, Figure 2. It is therefore a surprise to discover that musicians are unenthusiastic towards low reflectors above them. The difficulty appears to be that a reflector not only provides useful reflections but also disturbing reflections.

A musician needs to be able to hear his own sound and that of his colleagues, hearing self and others. But ‘others’ includes players who are nearby and those that are distant. It appears

that musicians want to be able to hear all their colleagues and the sound from nearby musicians can easily mask sound from those further away. Introducing an overhead reflector does nothing to improve musicians’ ability to hear distant colleagues and may confuse the sound on stage.

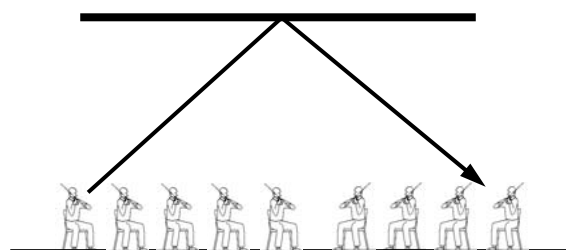


Figure 2. A reflector providing an overhead reflection across an orchestra.

From a questionnaire survey with orchestras, one clear correlation is found between the ratio of height/width of the stage volume and preference; high narrow stages are preferred. (The stage height is that up to the first reflecting surface.) From this, one can conclude that one can have too many reflections back to musicians and that lateral reflections are likely to be more useful. The instinctive reaction of placing a reflector above the stage may be the opposite of what is required. In several recent concert halls there are movable overstage reflectors; in several cases they are placed near their highest possible location, a choice which is in line with our findings.

The pioneering work on stage acoustics was conducted by Gade (1989). This led to the proposal of the measurable quantity called Support, which is essentially a measure of the amount of sound reflected back to the musician. Our study suggests that Support is not a very accurate measure for distinguishing between concert hall stages which the players like and dislike.

The history of concert hall design

The history of concert hall design is an intriguing one (Barron, 1993) and Beranek (1962 and 2004), particularly because there is a certain circularity involved. It is useful to divide this history into four periods:

Up to 1910	Design based on precedents
1910 – 1940	Era of pseudo-science and fan-shape plans
1950 – 1985	Period of experimentation
1985 -	Return to precedents

One overriding conflict arises with larger concert halls. To satisfy the reverberation criterion a large auditorium volume is needed. But one then finds that satisfying the other

requirements such as appropriate clarity and intimacy becomes frustrated at this scale. This can be called the **large concert hall problem**. The large concert hall problem is to provide sufficient early reflections for all seat locations in spite of large room volumes, which tend to remove useful reflecting surfaces away from seating areas. Most designs since 1960 have addressed the large concert hall problem by design of the seating layout and design of reflecting surfaces around seating areas.

The history of large concert halls begins in the 18th century with ballrooms, often in courtly palaces. Today we find the concert hall becoming the prestige urban building designed by world architects like Frank Gehry and Jean Nouvel. One of the particular interests of auditorium design is the manner in which the constraints imposed by housing thousands of listeners are accommodated in the overall design. The primary constraint is the need to provide all audience members with good sightlines to the stage.

This review concentrates on concert hall design in the 1960s and '70s comparing it with the situation today. It begins with a review of the state of acoustic knowledge around 1960 and on what principles acoustic consultants at the time might base a design.

Acoustic knowledge around 1960

The following lists the main events of acoustic significance up to the late 1970s.

- 1900 Sabine proposes the reverberation time
- 1953 Thiele proposes early-to-late ratio as a measure of intelligibility and clarity
- 1960 Beranek resolves absorption by seating
- 1962 Opening of Philharmonic Hall, New York
Publication of 'Music, acoustics and architecture' by Beranek
Proposal that the initial-time delay gap is crucial for concert hall listening
- 1965 Schroeder *et al.* propose the slope of the early part of the decay as a measure of reverberance (EDT)
- 1967 Marshall suggests that early lateral reflections are an important element for good acoustics (LF)
- 1971 Hawkes and Douglas demonstrate that concert hall listening is a multi-dimensional experience
- 1974 Reichardt suggests early-to-late index based on 80ms for music (C80)
- ~1975 Results from studies in Göttingen and Berlin using dummy heads become available
Importance of sound level and gain provided by an auditorium (G)

Sabine's work with reverberation time is very well known. Introducing the new concept of reverberation time presented however a new quantity which needed to be measured for all materials used in auditoria: the absorption coefficient. The most problematic 'material' was audience seating and seated audience. Sabine had the options of working with absorption

per person or an absorption coefficient based on material area. In the absence of much data he chose absorption per person. During the earlier decades of the 20th century, the seating standard (area per seat) gradually became more generous. This contributed to the absorption by seating being underestimated resulting in shorter reverberation times than optimum. The issue of audience absorption was resolved by Beranek (1960) who realised that working with an absorption coefficient was more reliable. An English example affected by this problem is the Royal Festival Hall, London of 1951 which at the time of opening had a reverberation time (RT) of 1.45 seconds. The inadequate auditorium volume has left this problem rather intractable; recent refurbishment only managed to increase the RT to 1.65 s.

With room acoustic simulation systems after 1950 the secrets of early reflections were investigated. The simulation systems consisted of an array of loudspeakers around a listening position in an anechoic chamber; reflections were simulated by introducing signal delays, initially with tape machines. Objective measures for intelligibility or clarity, the sense of reverberation (reverberance), and spatial impression were proposed. The key references for this research are listed below. In 1971, Hawkes and Douglas showed that concert hall listening was in fact a multi-dimensional process; this provided an important contextual framework for the listening experience.

While it took designers a while to assimilate the significance of individual results, it was only towards the mid-'70s that the results of research by two German groups in Göttingen and Berlin became known. Both used dummy heads (model heads with accurate outer ears and microphones in the ear canals) to make recordings in actual concert halls. The Göttingen group used anechoic recordings played through loudspeakers, while the Berlin group had access to the Berlin Philharmonic Orchestra (!). This was the first time that the priorities for concert hall listening were demonstrated, the work is well summarised by Cremer and Müller (1982). One can interpret the results of these studies as indicating the following five subjective characteristics as being most important:

- Clarity
- Reverberance (sense of reverberation)
- Source broadening
- Intimacy (degree of involvement of listener)
- Loudness

For the acoustic consultant, working only with reverberation time as a measurable and predictable parameter, there was the question of what room form is suitable for music listening. Sabine's work only really determines the gross volume of a concert hall. During the early half of the 20th century, many halls with fan-shape plans had been built. This plan form accommodates the most audience within a particular angle from the stage and worked well for cinema, the new entertainment of the time. Slowly the poor acoustic quality of the fan-shape plan has become apparent.

The consultant was left with two options. The first of these was to copy details from precedents with good acoustic reputations. This however is problematic. The acoustics of the Musikvereinssaal in Vienna (1870) are often praised but which characteristic in their design should one copy?

Gross proportions (length:width:height)

Construction materials

Parallel side walls

Hall width

Surface decoration (scattering surfaces)

Suspended chandeliers

In retrospect, the 2nd, 3rd, 4th and 5th now seem relevant, but this was not obvious 45 years ago.

The 2nd option for consultants was to concentrate on one of the new discoveries. Either strategy involved considerable risks.

Concert halls built between 1960 and 1979

Several books document the details of important larger concert halls: Beranek (1962), Talaske et al. (1982), Barron (1993), Hoffman et al. (2003) and Beranek (2004).

1960 Festspielhaus, Salzburg: a design with large areas of uninterrupted seating and excessive width at 38m

1962 Fairfield Hall, Croydon, London: a hall whose design was aimed at avoiding the problems encountered with the Royal Festival Hall of 1951. Fins separating boxes and running across the ceiling had the effect of preventing early sound reaching the rear.

1962 Philharmonic Hall, New York: a troubled design with several details changed without the approval of the acoustic consultant. A large number of suspended reflectors were found not to reflect bass frequencies, which was also discovered were attenuated for sound travelling across audience seating. Suitable RT of ~2s. Poor balcony design. Possible example of subdivided acoustic space.

1963 Philharmonie Hall, Berlin: The first and most inspired vineyard terrace hall. Surfaces between seating blocks provide early reflections.

1966 de Doelen Concert Hall, Rotterdam: nearly all wall and ceiling surfaces are sound scattering, providing the equivalent of scattering surfaces to be found in 19th century concert halls. The plan is also inspired to ensure that early reflections reach all seating areas (see Figure 3 below). The acoustic consultants were Kosten and de Lange.

1971 Kennedy Center Concert Hall, Washington, DC.: one of the few rectangular plan concert halls from the period (acoustic consultant Cyril Harris).

1971 Finlandia Concert Hall, Helsinki: fan-shaped plan with disappointing acoustics. (The architect Alvar Aalto acted as his own acoustic consultant.)

1972 Town Hall, Christchurch, New Zealand: suspended reflectors mounted above the gallery to provide early lateral reflections. Other characteristics are a long reverberation time and a high degree of intimacy. (Acoustic consultant was Harold Marshall.)

1973 Sydney Opera House Concert Hall: the need to fit the auditorium within the famous shells rather compromised the design.

1976 Avery Fisher Hall, New York: the replacement for Philharmonic Hall with a parallel-sided design.

1977 Konserthus, Oslo: another compromised fan-shape plan, partly dictated by the available site.

1978 Boettcher Hall, Denver, Colorado: a large hall arranged in-the-round. Balance issues related to musical instrument directivity, especially singers.

1979 Muziekcentrum Vredenburg, Utrecht: again music-in-the-round with attendant balance issues.

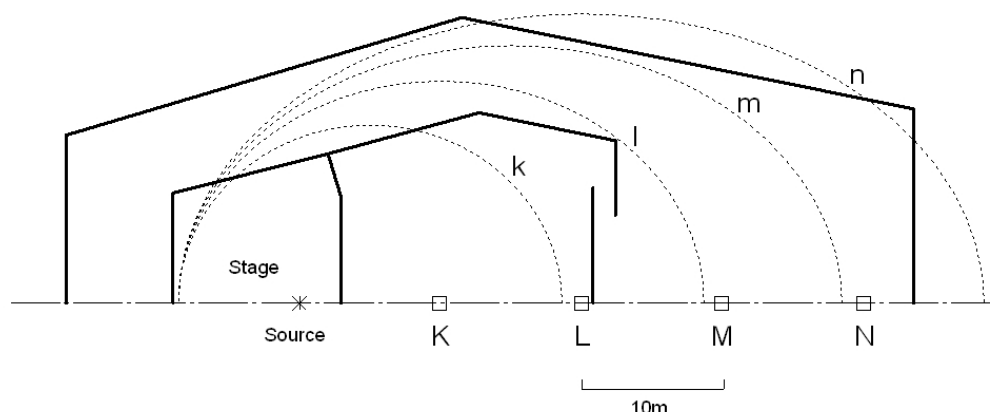


Figure 3. Suitable reflector positions to provide a 50 ms delayed reflection for four receiver locations K – N. Reflectors should be tangential or inside the relevant ellipses k – n.

In conclusion about auditoria from this period, one can comment that it was a great period for experimentation, which offer valuable lessons for design. Several concert halls however do have disappointing acoustics. Following the primacy of reverberation time, one might also add that the search for the second parameter remained basically unresolved.

The plan of de Doelen concert hall can be interpreted by considering the locations of reflecting surfaces to provide early reflections. As shown in Figure 3, the ellipse labeled 'k' is relevant to the receiver position 'K' etc. If a reflector is tangential or inside the ellipse, there will be an earlier reflection which arrives at 'K' with a delay of no more than 50 ms. It can be seen that by having a lower Stalls seating area, early reflections can be provided for seat locations both close and distant from the stage.

Contemporary understanding of concert hall acoustics

Following the research work of the 1970s and '80s, a consensus view has been reached with the five subjective qualities listed above. Objective quantities now exist relating to each of these, as listed in Table 1.

Subjective quality	Objective measure
Clarity	Clarity index (C_{80})
Reverberance	Early decay time (EDT)
Intimacy	Sound strength (level)
Source broadening	Early lateral fraction and strength
Loudness	Sound strength and source-receiver distance

Table 1. Important subjective qualities and objective measures related to them.

The various objective quantities are now contained in the Standard ISO3382, Part 1.

These objective quantities can be measured/predicted in computer simulation models or acoustic scale models. For acoustic scale models, scales of 1:10 to 1:50 have been used. The former can provide musical samples for subjective assessment. The equivalent for computers is known as auralisation. With these tools the risk of poor acoustics is much diminished.

Contemporary concert hall design

A major change in approach to concert hall design occurred in the late 1980s. This can be mainly attributed to the late Russell Johnson of Artec Consultants, New York (see their website). Having designed a series of halls with strong lateral reflections, he turned in the 1980s definitively to rectangular halls. The first of these was the Eugene McDermott Concert Hall, Dallas of 1989, shortly followed by the Birmingham Symphony Hall, England (1991). As well as establishing a characteristic plan form with parallel side walls and theatre-type curved balcony fronts, these halls have a large movable reflector above the stage and reverberation chambers. The Lucerne Culture and Congress Centre Concert Hall (1999) is a further development (see Beranek, 2004).

The change of approach relates to clients becoming aware that the reputation of a new auditorium was linked to its acoustics and that acoustics perhaps influenced future financial success. The status of the acoustician has become raised relative to the architect allowing them to influence auditorium design more than previously. With these changes came greater responsibility for acoustic consultants, which led to fewer risks being taken. By this time, two concert hall forms had emerged as acoustically reliable: the **rectangular plan** and the **terraced hall**. Experience with rectangular halls had of course been much more extensive. In Figure 4 one sees however that the rectangular plan was virtually unused between about 1910 and 1970. The desire to move on from the architecture of the 19th century was obviously an influence in this case. (The halls represented in Figure 4 are listed in Barron, 2006.)

The second precedent, the terraced hall, has a much shorter history. Pioneered by the architect Hans Scharoun with Prof. Cremer as consultant, the Berlin Philharmonie of 1963 (2340 seats) was a seriously radical design (Cremer, 1964). Audience surrounds the orchestra platform and is divided into blocks of 100 – 200 seats. This provides a more involving experience for both performers and audience. From an acoustic perspective, Cremer knew of the importance of early reflections, which necessitated in this design placing the audience blocks at different levels so that surfaces separating them could be used to provide additional early reflections. For this reason, the form is often referred to as having vineyard terraces. The design challenge is however demanding, particularly to maintain uniformity throughout the seating area.

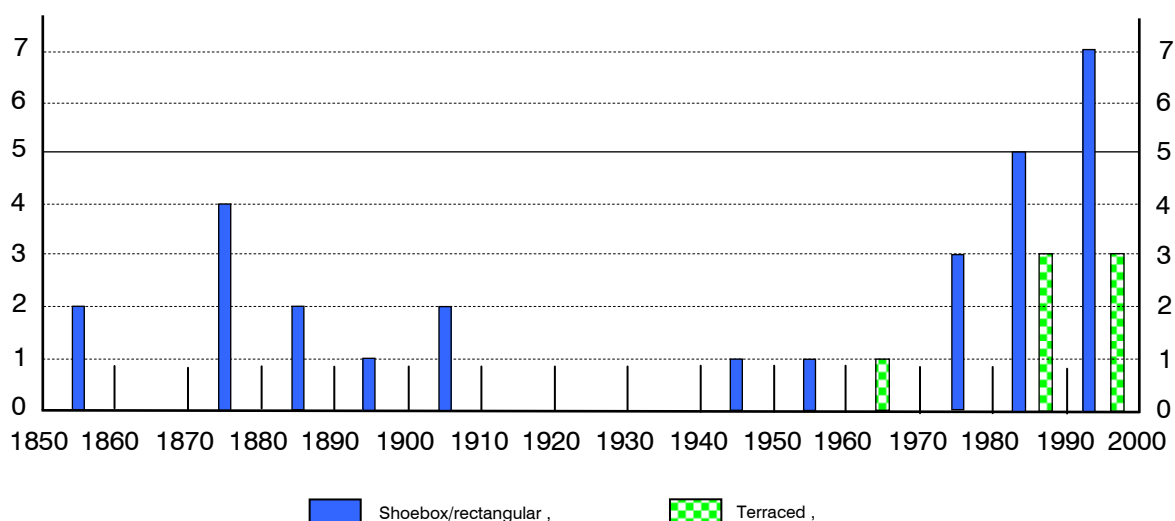


Figure 4. Numbers and dates of rectangular and terraced halls, taken from a representative list of halls (Barron, 2006).

With two concert hall forms dominating present design, what are the pros and cons of these two forms?

The rectangular concert hall	
Advantages:	Acoustics are pretty reliable
	A known 'quantity' expected to have good acoustics
	Liked by many musicians
Disadvantages:	Formal relationship of audience to performers
	Limited involvement of the audience
	'Looking through a tunnel' from rear audience seats
	Poor sightlines at high levels on the sides
	Limited seat capacity

Table 2. The advantages and disadvantages of the rectangular concert hall form.

The terraced concert hall	
Advantages:	Acoustician has more control over acoustics
	Involving relationship between performers and audience
	Good sightlines
	Larger audience capacity possible
	Greater freedom in design
Disadvantages:	Poor balance for audience to the sides of the stage
	Demanding to get good acoustics

Table 3. The advantages and disadvantages of the terraced concert hall form.

The safe solution is the rectangular hall, while the terraced hall offers greater freedom of design and potentially more exciting performance spaces.

Over the last 20 years, the size of several acoustic consultancies has grown to the point where they now dominate 'the market'. Not surprisingly, many clients feel more confident using a large as opposed to a small consultancy. A by-product of this development is that less information is available in the public domain regarding the principles and techniques that consultants are using. To what extent is a scientific approach being used? Are either computer simulation models or physical scale models being employed? Of course, auditorium acoustic design is both an art and a science; features which appear valuable can be repeated and *visa versa*. Secrets are likely to take longer to emerge than before.

Conclusions

The progress in acoustic design between the '60s and '70s on the one hand and the present is obvious. The predictability of acoustic quality is much greater than it was 40 years ago. However current designs are dominated by precedents and at least in the case of the rectangular hall one observes a certain circularity.

Not all modern halls though conform to the two dominant precedents. The new Philharmonie Concert Hall for Paris, due to open in 2012, is a new attempt to solve the large concert hall problem. The problem can in many cases be reduced to the desire to achieve both clarity and a strong sense of reverberance. In the case of the Paris hall, the seating and associated surfaces are suspended within a larger enveloping volume; the latter will provide a longer reverberation time than possible without separating the surfaces responsible for the early reflections.

One unresolved question is what is the subjective value of scattering room surfaces? At present there is no agreed subjective quality associated with the scattering surface.

We can look forward at some stage to more experimentation in the future?

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